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CRITERIA AND STANDARD TEST METHODS FOR THE SELECTION OF ELECTRIC CABLES, WIRES AND INSULATED PARTS WITH RESPECT TO FIRE SAFETY AND RADIATION RESISTANCE

This Safety Instruction is published by the TIS Commission as defined by the CERN Safety Policy document SAPOCO/42 and under the provisions of the CERN Safety Codes. It is based on:

- The CERN Fire Code E
- Standards and publications of the IEC and other internationally recognized bodies
- The CERN Electrical Safety Code C1
- Recommendations of the Materials and Cable Working Group on fire and radiation resistant cables.

This inter-divisionary Working Group, formed in 1977, periodically updates this Safety Instruction in line with the latest Standards and materials available, resulting in the present version.

The first edition of IS 23 was published together with the Code C1 and formally approved by SAPOCO in December 1984.

This Instruction is intended to ensure a very high level of safety and must be applied to all new cable installations at CERN, including the addition of cables to existing installations. CERN attaches an increased importance to the hazards associated with smoke, toxicity and corrosivity from burning plastics.

In particular, IS 23 must be fully taken into account in the specifications for all cable purchases. It is also applicable to the CERN infrastructure such as cranes, lifts, ventilation plants, etc.

Exceptions can only be authorized by the Leader of the Division concerned in consultation with the Leader of the TIS Commission. In such cases, alternative preventive measures will normally be required and must be carefully studied and agreed. A complete record of the installation of all cables and materials not conforming to IS 23 must be kept by the Group Leader or GLIMOS responsible for the installation.

CONTENTS

1 INTRODUCTION AND SCOPE

This instruction prescribes standard test methods for selecting suitable materials for the insulation and sheathing of power, control and signal cables and wires with respect to their resistance to fire and ionizing radiation. It summarizes the required properties for the different materials and cable types, giving criteria for their specification, selection and testing. It is applicable to all kinds of cables and wires and other insulated parts to be used in CERN installations, including equipment for prototypes, tests and experiments (power, control, signal, high and low voltage, high and low frequency, fibre optics, etc.).

2 REQUIRED PROPERTIES OF CABLE INSULATING MATERIALS

The requirements for all types of cables are the following:

- Electrical, mechanical, thermal and environmental endurance properties conforming to the appropriate standards
- Flame retardant characteristics satisfying the relevant standards
- Halogen and sulphur free
- Low smoke density
- Low toxicity of gases from fires
- Low corrosivity of gases from fires
- Retention of functional capabilities up to an integrated radiation dose of 10^6 Gy for general purpose cables and 10^7 Gy for special radiation resistant cables.

Note: The requirements of low smoke density, low toxicity and corrosivity of gases from fires exclude some very commonly available materials such as polyvinyl chloride (PVC), chlorosulphonated polyethylene (Hypalon®), polychloroprene (Neoprene®), fluorocarbons (e.g. Teflon®) and other halogenated or sulphur containing compounds.

3 CRITERIA FOR THE SPECIFICATION AND SELECTION OF CABLE INSULATING MATERIALS

3.1 Applicable standards

The required properties are described in this section and summarized together with the standards in Table 1 and Appendix 1. Independent laboratories capable of carrying out fire, smoke and toxicity tests are listed in Appendix 2.

3.2 Flame propagation and fire resistance

Electric cables and wires can be classified in three categories with increasing fire resistance:

i) flame retardant cables tested under single configuration (IEC 332-1 and 332-2),
ii) flame retardant cables tested under bunched configuration (IEC 332-3),
iii)fire resistant cables (IEC 331).

A distinction is made between the fire properties of materials and those for cables. Only categories (i) and (ii) will be considered in this document. Cables in Category (iii) are those which must continue to function for a defined time during and after a fire. They are mainly used for safety installations and will not be considered further in the present document.

3.2.1 Materials

The value of the temperature index measured according to BS 2782, Part 1, shall be greater than 260°C for all materials and compounds except primary insulations and dielectrics.

Note: Cables with sheath materials satisfying this requirement must also satisfy the fire test for the finished product.

3.2.2 Finished cables

Small, single-core, insulated wires with conductors smaller than 0.8 mm diameter (0.5 mm^2) shall be tested according to IEC 332-2.

Single-core insulated wires with conductors greater than 0.5 mm^2 and all multiconductor cables, round or flat of any dimension, shall pass IEC 332-1. For flat cables the flame shall be applied to one edge of the flat cable with the axis of the burner tube in the same plane as the major axis of the cables.

All types of finished cables having an outer diameter exceeding 10 mm must pass the IEC 332-3 test, Category CF.

3.3 Smoke density

Samples of finished cables, wires or sheath materials shall be tested according to ASTM E 662. The required value of the specific optical density, D_s, is less than 250 in both the flaming and non-flaming modes.

For all major CERN cable contracts the cables must in addition pass the more extensive tests IEC 1034, Part 1 and Part 2.

3.4 Toxicity of gases from fires

The Airbus Industry Technical Specification test method described in ATS 1000.001 shall be applied. The concentration of toxic gases released shall be below the limits specified in Table 1.

3.5 Corrosivity of gases from fires

All constituent materials of cables, including tapes and fillers, must be halogen and sulphur free (less than 0,1% by weight). The materials must pass the IEC 754-2 test with pH greater than 4.0 and conductivity less than 100 µS/cm.

3.6 Radiation resistance

A distinction is made between general purpose cables and special cables used only in high-radiation areas.

3.6.1 General purpose cables

For cables with common elastomeric or thermoplastic insulation and sheath materials the Radiation Index [1] (RI) defined in IEC 544-4 shall be greater than 5.7. The critical property is the elongation at break which, measured according to ISO 37, must be larger than 50% of the initial value after an exposure to an integrated dose of 5×10^5 Gy, at a dose rate > 1 Gy/s.

3.6.2 Special radiation resistant cables

The recommended insulating material for power cables is a mica tape containing a small percentage of organic binder with a corrugated aluminium tube as outer sheath.

Note: Such a cable has been successfully installed and used since 1980 in the SPS neutrino target area.

An entirely inorganic insulation such as magnesium-oxide or aluminium-oxide is an alternative solution for power cables.

For control and signal cables, polyimide tapes (e.g. Kapton®) are used as insulation with a binder of polyimide lacquer. The outer sheath is silicone polyetherimide copolymer.

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1. RI = $\log_{10}$ of the absorbed dose in gray above which the appropriate critical property value has reached the end-point criterion.

Note: The radiation resistance achieved for polyimide insulated control cables is about 5×10^7 Gy, whereas for mica insulated power cables it is above 10^8 Gy

3.6.3 Optical fibre cables

Common optical fibre cables are very sensitive to radiation; it is recommended not to use them in radiation areas. Special radiation resistant optical fibres with radiation-induced attenuation of less than 20 dB/km at 10^4 Gy are available on the market.

3.7 Existing materials satisfying the specified criteria

3.7.1 Power cables

The specification of an ethylene propylene rubber polymer (EPR or EPDM) should be used for both the insulation and the outer sheath of power cables.

Ethylene vinyl-acetate (EVA) or a copolymer of polyolefin may be accepted as an alternative if the properties are equivalent to those of EPR. In view of the fact that these materials show a faster degradation after long-term irradiation than EPR, this option is not recommended for use of power cables in radiation areas.

A polyethylene insulation may be used for high voltage cables where its electrical properties represent a distinct advantage.

3.7.2 Control and signal cables

The preferred dielectric and/or insulation material is polyethylene (PE). For the outer sheath a flame retardant material such as ethylene vinylacetate (EVA) or a polyolefin copolymer should be used.

3.7.3 Miniature wires and cables for electronics

Miniature wires are used in electronics circuits where there are often severe space limitations and functional requirements. For these cables and wires it is recommended that the insulation and/or sheath be based on polyimide (e.g. Kapton®), polyetherimide (e.g. Ultem®), polyetherether ketone (PEEK), polyphenylene oxides (Noryl®) or similar materials.

4 INSULATING MATERIALS USED IN ELECTRICAL AND ELECTRONIC EQUIPMENT

For obvious reasons, the same rules should also be applied when considering associated equipment (see, for example, Appendix 3 for a typical specification).

Note: Recommendations for the use of plastic and synthetic materials in areas where the products of combustion in a fire may cause material damage or threaten the health or life of affected persons are given in CERN Safety Note No 11.

5 PROCUREMENT OF MATERIALS AND CABLES

Large quantities of power, control and signal cables have been purchased by CERN in the Member States in conformity with the criteria specified in the present document and the predecing editions.

All cables and wires in the CERN stores have been replaced by halogen free types.

In order to facilitate the ordering of cables conforming to the specified criteria, the specialists in ST-IE Group can be consulted by CERN users. Clear specifications for all enquiries and orders are essential to ensure that the material delivered has the required properties.

TABLE 1
Required properties for the selection of electric cables and wires with respect to fire safety and radiation resistance

PROPERTY	STANDARD*	REQUIREMENTS	REMARKS
Flame and firepropagation	IEC 332-2IEC 332-1	PassPass	Applies to all single wires.Applies to all cables and to all single wires > 0.5 mm^2
	IEC 332-3	Pass	Applies to all cables with outer diam. > 10 mm, Category CF
Fire resistance	IEC 331	Pass	For cables with special safetyfunc-tions (eg. emergency lighting, alarms, lifts, etc.)
Smoke density For all cables	ASTM E 662(or ASTM F 814)IEC 1034 - 1 and 2	For all major CERN cable contracts non-flaming	D_s < 250 in the flaming and modesPass
Toxicity of fire gases	ATS 1000.001	HF < 100HCl < 150 HCN < 150SO_2 + H_2 S < 100 CO < 3500 NO + NO_2 < 100	Mean value in ppm of at least 3 samples obtained within 4 minutes under flaming and non-flaming conditions
Corrosivity of fire gases	IEC 754-2	pH > 4 and conductivity < 100 mS/cm	Cables shall be halogen and sulphur free (less than 0.1 % by weight).
UV Resistance C, 10 days, 40°C	IEC 68-2-5	No discolorationNo stickiness	Procedure
Radiationresistance Index > 4	IEC 544-2 and Elongation at break (ISO 5.7		Radiation 37) 50% of initial value at absorbed dose of 5.10^5 GyTest at high-dose rates (greater than 1 Gy/s).
Temperature indexof sheath < 50 mm	BS 2782, Part 1	Pass	FT > 260°C Length burnt

* See Appendix 4.

SUMMARY OF REQUIRED PROPERTIES FOR THE SELECTION OF ELECTRIC CABLES, WIRES AND INSULATED PARTS WITH RESPECT TO FIRE SAFETY AND RADIATION RESISTANCE

A. ALL CABLES AND WIRES

a) Flame retardant characteristics satisfying the appropriate standards
b) Halogen and sulphur free
c) Low smoke density
d) Low toxicity of fire gases
e) Low corrosivity of fire gases
f) Retention of functional capabilities up to an integrated radiation dose of 10^6 Gy.

Note on b), c), d) and e): These requirements exclude some very commonly used materials such as PVC, Hypalon®, Neoprene®, fluorocarbons and other halogenated or sulphur containing compounds (e.g. Teflon®).

Note on f): This requirement is considered satisfied if, after an exposure of the insulation and sheath material to an integrated dose of ionising radiation of 5×10^5 Gy, the elongation at break (ISO 37) is greater than 50% of the initial value. The irradiation is performed at high dose rates (greater than 1 Gy/s). The Radiation Index (RI)* according to IEC 544-4 is then > 5.7. The supplier must either prove this radiation resistance or supply test samples in order to carry out radiation tests by CERN.

The supplier must provide test results or certificates to prove that the cable satisfies the test requirements defined in Table 1.

B. POWER CABLES

Both the insulation and outer sheath material should preferably be made of EPR or EPDM. Suppliers may propose alternative materials for insulation and outer sheaths (e.g. EVA or polyolefin). They must, however, prove that all specification requirements are fulfilled.

C. CONTROL AND SIGNAL CABLES AND WIRES

The recommended material for insulation is PE and for the outer sheath a flame retardant material such as EVA or a polyolefin copolymer.

D. ELECTRICAL AND ELECTRONIC EQUIPMENT

Internal wiring of electrical and electronic equipment should follow the same rules as applied for power, control and signal cables. The same applies for all other kinds of organic materials used in this equipment such as connectors, conduits, terminal boards, frames, covers, spacers, etc. (see Appendix 3).

* RI = $\log_{10}$ of the absorbed dose in gray above which the appropriate critical property value has reached the end-point criterion.

A SELECTION OF INDEPENDENT LABORATORIES CAPABLE OF CARRYING OUT FIRE, SMOKE OR TOXICITY TESTS

1. RAPRA
   Shawbury, Shrewsbury, Shropshire SY4 4NR,
   England
   Tel. +44 939 250 383,
   Fax +44 939 251118
   Telex 35134

2. Institut National des Industries Extractives
   200, rue du Chera
   B - 4000 LIEGE
   Tel. +32 41 527 150
   Fax +32 41 524665

3. Norwegian Fire Research Laboratory
   SINTEF
   N - 7034 TRONDHEIM-NTH
   Tel. +47 7 595190, 59 3000
   Fax +47 7 592480
   Telex 55620

4. Warrington Fire Research Centre (London) Ltd.
   101 Marsh Gate Lane
   GB - LONDON E15 2NQ
   Tel. +44 81 519 8297
   Fax +44 81 519 3029

5. CESI (Centro Elettrotecnico Sperimentale Italiano)
   Via Rubattino 54
   I - 20134 MILANO
   Tel. +39 2 2125 1
   Fax +39 2 2125440

6. N.V. KEMA
   P.O. Box 9035
   NL - 6800 EPARNHEM
   Tel. +31 85 569111
   Fax +31 85 514922

Test Standards and Specifications for Electromechanical Components of Electronic Equipment

(Connectors, terminal boards, cards, foils, films, tapes, conduits, tubings, mouldings, coatings, supports, frames, covers and similar parts)

	TESTSTANDARD (1)	REQUIREMENTS
Flame propagation	IEC 695-2-2	Duration of flame application 60 s
a) Needle-flame test		unless otherwise stated according to
		Clause 5. Time to extinction: 30 s *Damaged length (mm) must be measured*
b) Flammability test	IEC 707 orUL 94V	FV0 or FV194 V0, 94V1
c) Temperature Index	BS 2782, Part 1	FT >260°C. Length burnt < 50 mm.
Smoke density	ASTM-E-662	Ds < 250 for flaming and non-flaming
	or	modes
	ASTM-F-814	
ToxicityToxicity of fire gases	ATS 1000.001	HF < 100 Mean value in ppm HC1 < 150 of at least 3 samples HCN < 150 obtained within $SO_2 + H_2S$ < 100 4 minutes under flamingCO <3500 and non-flamingNO + NO_2 < 100 conditions
Corrosivity Corrosivity of fire gases	IEC 754-2	pH > 4conductivity <100 µs/cm
Radiation resistance	IEC 544Parts 2 and 4	Tensile strength or Flexural strength
		or Elongation at break: 50% of initial
		value at absorbed dose of 5.10^5 Gy at
		high dose rates(greater than 1 Gy/s) when applicable

*full details and numerical values must be supplied by the manufacturer

(1) **Standards** - see Appendix 4. (Alternative ISO, IEC and other International Standards or National Standards may be considered in agreement with CERN, and should preferably be selected from the survey of test methods listed in IEC 695-3-1 section 5 and Appendix A, or in the IEC Safety Handbook.)

QUOTED STANDARDS*
(the most recent version will apply)

ASTM E 662 & ASTM F 814	Standard Test Method for Specific Optical Density of smoke generated by Solid Materials
ATS 1000.001	Airbus Industry Technical Specification, Fire-Smoke-Toxicity (FST) Test Specification
BS 2782	Part 1, Plastics: Methods 143A and 143B. Determination of Flammability. Temperature of materials.
IEC 68-2-5	Simulated solar radiation at ground level
IEC 331	Fire-resisting characteristics of electric cables
IEC 332	Tests on electric cables under fire conditions 332-1 Part 1: Test on a single vertical insulated wire or cable 332-2 Part 2: Test on single small vertical insulated copper wire or cable 332-3 Part 3: Tests on bunched wires or cables Amendments N° 1 and 2
IEC 544	Guide for determining the effects of ionizing radiation on insulating materials 544-1 Part 1: Radiation interaction 544-2 Part 2: Procedures for irradiation and test 544-4 Part 4: Classification system for service in radiation environments
IEC 695	Fire hazard testing Part 2-2: Needle flame test Part 3-1: Examples of fire hazard assessment procedures
IEC 707	Methods of test for the determination of the flammability of solid electrical insulating materials when exposed to an igniting source
IEC 754-2	Test on gases evolved during combustion of electric cables

IEC 1034 Parts 1 and 2	Test for the measurement of smoke density of electric cables burning under defined conditions
ISO 37	Rubber, vulcanized - Determination of tensile stress-strain properties
UL 94V	Standard for flammability of plastic materials for parts in devices and appliances

* ASTM = American Society for Testing and Materials
ATS = Airbus Industry Technical Specification
BS = Bristish Standard
IEC = International Electrotechnical Commission
ISO = International Standardization Organization
UL = Underwriters Laboratories